LETTER

ConSet: Hierarchical Concurrent Path Setup Scheme in Multi-Layer GMPLS Networks

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SUMMARY This letter proposes a hierarchical label-switched path (LSP) setup scheme, called ConSet, for multi-layer generalized multi-protocol label switching (GMPLS) networks. ConSet allows a Path message to be transmitted to the downstream neighbor node without waiting for the establishment of the higher-order LSP. Confirmation of the establishment of the higher-order LSP is performed at the ingress node of the higher-order LSP before a Resv message of the lower-order LSP is transmitted to the upstream neighbor node. ConSet is able to set up hierarchical LSPs faster than the sequential scheme.

key words: *GMPLS, signaling, RSVP, multi layer*

1. Introduction

Generalized Multi-Protocol Label Switching (GMPLS) is being developed in the Internet Engineering Task Force (IETF) [1], [2]. It is an extended version of Multi-Protocol Label Switching (MPLS). While MPLS was originally developed to control packet-based networks, GMPLS controls several layers, such as IP-packet, Time-Division-Multiplexing (TDM), wavelength, and optical-fiber layers, in a distributed manner [3].

A photonic MPLS router has been developed by NTT [4]. It offers both IP/Multi-Protocol Label Switch (MPLS) packet switching and wavelength-path switching. Wavelength paths, called lambda label switched paths (lambda LSPs) are set and released in a distributed manner based on GMPLS. Since the photonic MPLS router has both types of switching capabilities and can handle GMPLS, it enables us to create, in a distributed manner, the optimum network configuration with regard to the resources of IP and optical networks. Multi-layer traffic engineering, which yields the dynamic cooperation of IP/MPLS and optical layers, is required to provide IP services cost-effectively [5], as shown in Fig. 1.

The concept of hierarchical LSPs was introduced in [6]. The GMPLS signaling protocol RSVP (Resource ReSerVation Protocol) allows hierarchical LSPs to be set up. When a new lower-order LSP is set up, the lower-order LSP setup triggers the establishment of a higher-order LSP, if it does not exist; the lower-order LSP uses the higher-order LSP as a link along the lower-order LSP. Here, the higher-order LSP is taken as a TE link of the lower-order LSP. The bandwidth of the high-order LSP is equal to or larger than that of the lower-order LSP.

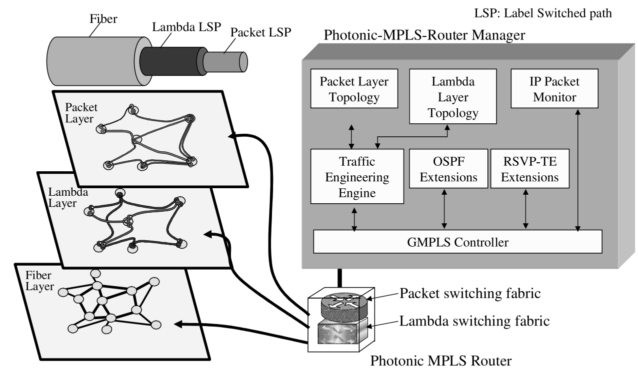

Fig. 1 Multi-layer GMPLS network controlled by photonic MPLS router.

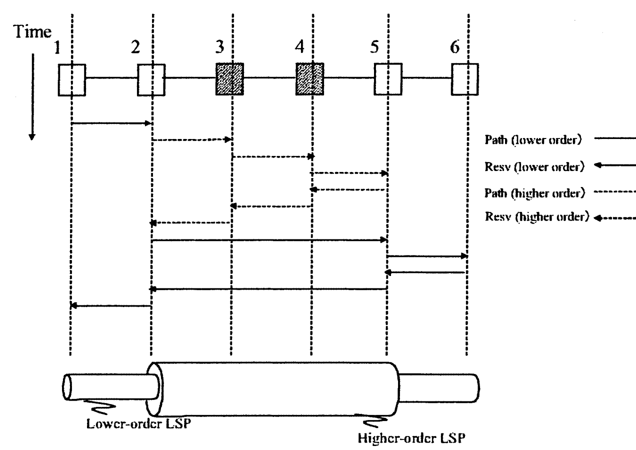

Fig. 2 Sequential scheme.

A hierarchical-LSP setup scheme was described in [2]. Figure 2 shows an example of the hierarchical-LSP setup scheme based on GMPLS RSVP. Node 1 transmits a Path message to node 2 to setup a lower-order LSP. The lower-order LSP setup triggers the establishment of a higher-order LSP as a link at node 2, which is an ingress node of the higher-order LSP. The higher-order LSP is setup from node 2 to node 5 by way of node 3 and node 4. Node 2 waits to transmit a Path message of the lower-order LSP to the next hop node, node 5, until it (node 2) receives a Resv mes-

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sage from the higher-order LSP. In other words, the Path message of the lower-order LSP is transmitted to the downstream neighbor node only after a higher-order LSP is established. We call this scheme the sequential scheme.

Note that, in an hierarchical LSP example presented in Fig. 1, a packet LSP and a lambda LSP correspond to the lower-order LSP and the higher-order LSP, respectively. In the following, we use the terms of "lower-order LSP" and "higher-order LSP" when describing general signaling procedures.

The sequential scheme is possible within the existing GMPLS RSVP protocol [7], [8]. However, it takes the sequential scheme a long time to establish a lower-order LSP, especially when the number of hierarchical levels is large and/or when the hop number of the high-order LSP is large.

This letter proposes ConSet, a concurrent a hierarchical-LSP setup scheme. ConSet allows a Path message to be transmitted to the downstream neighbor node without waiting for the establishment of the higher-order LSP. The confirmation of the establishment of the higher-order LSP is performed at the ingress node of the higher-order LSP before a Resv message of the lower-order LSP is transmitted to the upstream neighbor node. ConSet can set up hierarchical LSPs faster than the sequential scheme.

2. Concurrent Scheme

We describe the use of ConSet in setting up a unidirectional LSP for simplicity, but it also supports bidirectional LSP setup.

Figure 3 shows the ConSet procedure. Note that, for both higher-order and lower-order LSP setup, we assume that ConSet allocates resources when Resv messages are processed.

Node 1 transmits a Path message to node 2 to setup a lower-order LSP. When node 2 receives the Path message, it initiates the establishment of a higher-order LSP, if necessary, as a link of the lower-order LSP. Node 2 does not allocate the resource of the lower-order LSP when the Path message is processed even if it initiates higher-order LSP establishment. Node 2 allocates the resource of the lower-order LSP when a Resv message is processed. Node 2 is the ingress node of the higher-order LSP and a transit node of

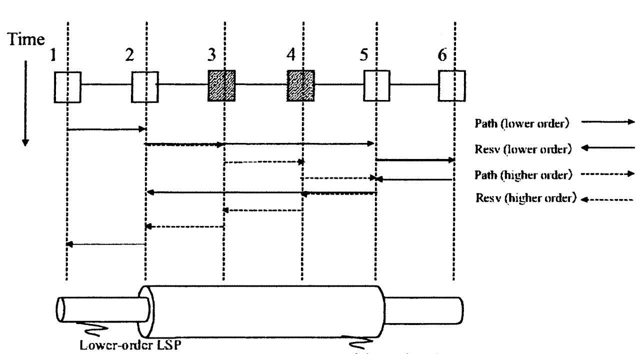

Fig. 3 ConSet.

the lower-order LSP. Node 2 transmits the Path message of the lower-layer LSP to its downstream neighbor node, which is node 5, without waiting for confirmation of the establishment of the higher-order LSP. In other words, node 2 does not wait to receive a Resv message for the higher-order LSP before it transmits the Path message of the lower-order LSP to its downstream neighbor node.

When node 5 receives the Path message of the lower-order LSP, the node must not issue a PathErr message, even if the higher-order LSP has not been established between it and node 2. This is because the higher-order LSP is in the process of being established.

When the destination node, node 6, receives the Path message of the lower-order LSP, it also does not issue a PathErr message even if the link, i.e., higher-order LSP, has not been established between it and its upstream neighbor node. The destination node issues a Resv message for the lower-order LSP, whether the higher-order LSP has been established between it and the upstream neighbor node or not.

When a node receives a Resv message of the lower-order LSP, the node must not issue a ResvErr message even if the higher-order LSP has not been established between the node and its downstream neighbor node, provided that the time elapsed since the first Resv message of the session was received at the node, has not exceeded a guard time, which is defined for ConSet. In this case, the node receiving the Resv message ignores and discards it. A node receiving a Resv message for the lower-order LSP transmits a Resv message to its upstream neighbor node after the higher-order LSP is established between the node and the downstream neighbor node, in other words, after the node receives a Resv message of the higher-order LSP, provided that the elapsed time has not exceeded the guard time.

If the ingress node receives a Resv for the lower-order LSP, the lower-order LSP is established after the higher-order LSP is established between the ingress node and the downstream neighbor of the lower-order LSP.

Thus, ConSet is able to set up hierarchical LSPs faster than the sequential scheme. Since these resource reservation mechanisms for different layers as described above are common, which means that resources for each layer are allocated when Resv messages are processed, ConSet can be applied to more than two layers.

Next, we describe examples of the failure of lower-order LSP setup. Since ConSet allows a Path message of the lower-order LSP to be transmitted to the downstream neighbor node without waiting for the establishment of the higher-order LSP, failure to establish the higher-order LSP should quickly stop the procedure for the lower-order LSP setup.

Figures 4 and 5 shows two failure cases. In both cases, when node 4 receives the Resv message of the higher-order LSP from node 5, it fails to reserve a resource for the higher-order LSP in a link between node 3 and node 4.

In case 1, as shown in Fig. 4, node 4 issues PathErr and ResvErr messages to node 3 and node 5, respectively. The PathErr and ResvErr messages are propagated to the ingress node, node 2, and the egress node, node 5, respectively. As soon as node 5 receives the ResvErr message of the higher-order LSP, it issues PathErr and ResvErr messages of the lower-order LSP, because the lower-order LSP uses the higher-order LSP as a link. As a result, reserved resources for the lower-order LSP are released. Note that node 1 may issue a PathTear message after it receives the PathErr message of the lower-order LSP, but this PathTear message is not depicted in Fig. 4.

In case 2, as shown in Fig. 5, node 4 fails to issue PathErr and ResvErr messages to the neighbor nodes due to some unexpected problem. If the time elapsed since the first Resv message of the lower-order LSP was received at node 2, exceeds a guard time known to the node, node 2 judges that the higher-order LSP could not be established. Node 2 then issues PathErr and ResvErr messages of the lower-order LSP to the RSVP neighbor nodes, which are node 1 and node 5, respectively, to clear the RSVP states for the lower-order LSP. The RSVP states of the higher-order LSP are cleared later on by the RSVP soft-state mechanisms.

Thus, ConSet is able to clear outstanding states of the lower-order LSP, as soon as related nodes on the lower-order LSP route judge failure of higher-order LSP establishment. This mechanism requires each node to keep more RSVP states than the sequential scheme. This is because the RSVP states of the lower-order LSP must keep information on higher-order LSP establishment.

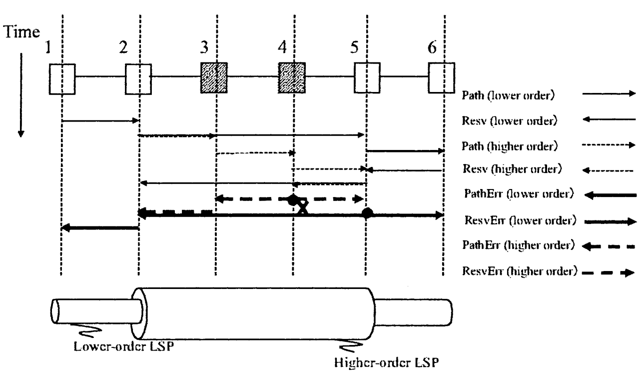

Fig. 4 Example of LSP setup failure. (case 1)

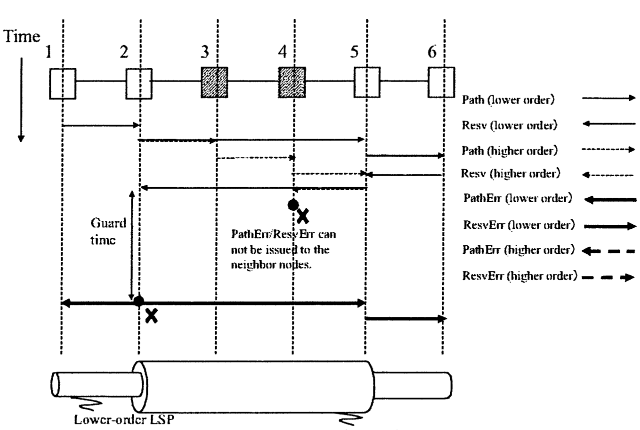

Fig. 5 Example of LSP setup failure. (case 2)

3. Comparison of LSP Setup Time

We compared LSP setup times for ConSet and the sequential scheme using the network model shown in Fig. 6. $N_{ingress,L}$ and $N_{egress,L}$ are the ingress node and egress node of a lower-order LSP. When the lower-order LSP is setup, an new higher-order LSP must be setup from $N_{ingress,H}$ to $N_{egress,H}$, where $N_{ingress,H}$ and $N_{egress,H}$ are the ingress node and egress node of the higher-order LSP. We assume that links for the lower-order LSP from $N_{ingress,L}$ to $N_{ingress,H}$ and those from $N_{egress,H}$ to $N_{egress,L}$ are already established. For the lower-order LSP, let h_{L1} and h_{L2} be the number of hops from $N_{ingress,L}$ to $N_{ingress,H}$ and that from $N_{egress,H}$ to $N_{egress,L}$,respectively. For the high-order LSP, let h_H be the number of hops from $N_{ingress,H}$ to $N_{egress,H}$.

We assume that LSP setup times are mainly dominated by the time to process signaling messages at each node. The transmission time of signaling messages is assumed to be included in the processing time. Therefore, only the processing time for signaling messages is discussed hereafter.

The setup times for the lower-order LSP and the higher-order LSP are denoted as T_s and T_c, respectively. The processing time at each node is defined as p. p is assumed to be the same at every node. Therefore, the LSP setup time is equal to (the number of nodes in which the signaling packets are processed at each node.) $\times$ p. T_s and T_c are given by,

$$T_s = (2h_{L1} + 4h_{L2} + 2h_H + 3)p \tag{1}$$

$$\begin{aligned} T_c &= \{2h_{L1} + \max(h_{L2} + 3, 2h_H + 1)\}p \\ &= \begin{cases} (2h_{L1} + h_{L2} + 3)p & \text{if } h_H \leq h_{L2} + 1 \\ (2h_{L1} + h_H + 1)p & \text{if } h_H > h_{L2} + 1. \end{cases} \end{aligned} \tag{2}$$

Note that when $h_H \leq h_{L2} + 1$, a Resv message of the higher-order LSP arrives earlier than a Resv message of the lower-order LSP. In this case, the arrival time of the Resv message of the lower-order LSP dominates the lower-order LSP setup time. This is the case presented in the example shown in Fig. 3. On the other hand, when $h_H > h_{L2} + 1$, the Resv message of the lower-order LSP arrives earlier than the Resv message of the higher-order LSP. In this case, the arrival time of the Resv message of the higher-order LSP dominates the lower-order LSP setup time. When $h_H = h_{L2} + 1$, the Resv messages of the lower-order and higher-order LSPs arrive at the same time. In the examples shown in Figs. 2 and 3, $T_s = 13p$ and $T_c = 9p$.

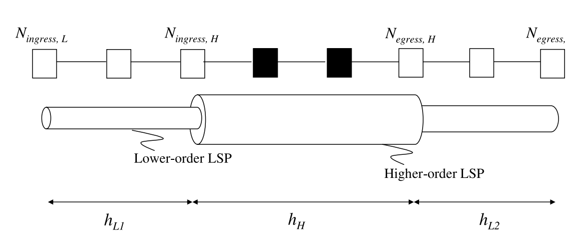

Fig. 6 Evaluation model.

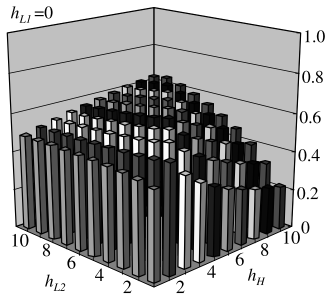

Fig. 7 Reduction effect for lower-order LSP setup time. ($H_{L1} = 0$)

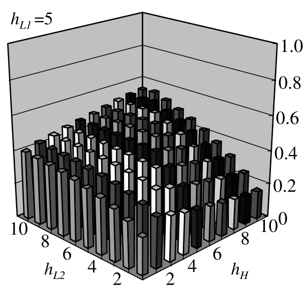

Fig. 8 Reduction effect for lower-order LSP setup time. ($H_{L1} = 5$)

The reduction effect, R, on the LSP setup time offered by ConSet compared to the sequential scheme is given by,

$$R = \frac{T_s - Tc}{T_s}. \tag{3}$$

Using Eqs. (1), (2), and 3, R is given by,

$$R = \begin{cases} \dfrac{2h_{L2} + 2h_H}{2h_{L1} + 4h_{L2} + 2h_H + 3} & \text{if } h_H \leq h_{L2} + 1 \\ \dfrac{4h_{L2} + 2}{2h_{L1} + 4h_{L2} + 2h_H + 3} & \text{if } h_H > h_{L2} + 1. \end{cases} \tag{4}$$

The numerical results gained from Eq. (4) using $H_{L1} = 0$ and $H_{L1} = 5$ are shown in Figs. 7 and 8, respectively. The difference in LSP setup times between the sequential scheme and ConSet, which is $T_s - T_c$, does not depend on H_{L1}. Therefore, the smaller H_{L1} is, the larger R is, as shown in Figs. 7 and 8. We also observe that a *ridge* appears when $h_H = h_{L2} + 1$. This means that ConSet is most effective when the Resv messages of the lower-order and higher-order LSPs arrive at the same time. For example, when $h_H = h_{L2} + 1 = 4$ and $h_{L1} = 0$, the LSP setup reduction effect is more than 60%.

4. Conclusions

This letter proposed a concurrent hierarchical-LSP setup scheme, called ConSet. ConSet allows a Path message to be transmitted to the downstream neighbor node without waiting for the establishment of the higher-order LSP. The confirmation of the establishment of the higher-order LSP is performed at the ingress node of the higher-order LSP before a Resv message of the lower-order LSP is transmitted to the upstream neighbor node. The LSP setup times for both the sequential scheme (conventional) and ConSet were analyzed. Numerical results showed that ConSet is able to set up hierarchical LSPs faster than the sequential scheme. We also observe that ConSet is most effective when the Resv messages of the lower-order and higher-order LSPs arrive at the same time.

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